

Flow Properties of Commercial Infant Formula Powders

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Abstract—The objective of this work was to investigate flow properties of powdered infant formula samples. Samples were purchased at a local pharmacy and differed in composition. Lactose free infant formula, gluten free infant formula and infant formulas containing dietary fibers and probiotics were tested and compared with a regular infant formula sample which did not contain any of these supplements. Particle size and bulk density were determined and their influence on flow properties was discussed. There were no significant differences in bulk densities of the samples, therefore the connection between flow properties and bulk density could not be determined. Lactose free infant formula showed flow properties different to standard supplement-free sample. Gluten free infant formula with addition of probiotic microorganisms and dietary fiber had the narrowest particle size distribution range and exhibited the best flow properties. All the other samples exhibited the same tendency of decreasing compaction coefficient with increasing flow speed, which means they all become freer flowing with higher flow speeds.

Keywords—flow properties, infant formula, powdered material

I. INTRODUCTION

THERE are numerous types of powdered infant formula available on the market today. Addition of probiotic microorganisms, dietary fiber, iron, omega 3 and 6 fatty acids, taurine and other beneficial supplements is intended to lure customers. Positive effects of these supplements are well investigated [1] – [3], however, only a few scientists did their research on flow properties of these infant formulas. Chuy and Labudza investigated the effects of heating rate, storage temperatures and water activity on surface caking and advanced caking of several dairy-based infant formula powders. They concluded that stability towards collapse and sticking decreased with increasing amounts of low-molecular weight carbohydrate [4].

Today, powdered infant formula is manufactured by more than a dozen firms in 40-50 processing plants worldwide. Some of the main challenges these plants face are those concerning nutritional and microbiological properties of infant formula, but they are also facing challenges concerning

powder flow properties. Some of these problems are easy dosing which requires uniformly low moisture content to prevent clumping and easy dissolving of the powder in water which requires a uniform particle structure and size distribution. Also, Codex Standard for infant formula, section A 3.5, Consistency and Particle Size states: When prepared according to the label directions for use, the product shall be free of lumps and of large coarse particles and suitable for adequate feeding of young infants [5].

The aim of this paper was to measure flow properties of five different infant formula samples bought at a local pharmacy. Cohesion index, compaction index, powder flow speed dependency and caking properties were determined using TA.HD Plus Powder Flow Analyzer manufactured by Stable Micro Systems, Surrey, UK. Particle size distribution was determined by sieving analysis using test sieves and the bulk density by weighing the sample, calculating the sample's volume and measurement errors with StatSoft Statistica software.

II. MATERIALS AND METHODS

A. MATERIALS

The study was carried out with different infant formula samples available on the Croatian market. Samples were purchased at a local pharmacy.

- Sample 1: Nestle Nan Lactose Free infant formula (manufactured by Nestle Nederland, The Netherlands)
- Sample 2: Aptamil 1 (manufactured by Nutricia Cuijk, The Netherlands), containing IMMUNOFORTIS™ dietary fiber
- Sample 3: Nestle Nan 1 H.A. Premium Gold (manufactured by Nestle Deutschland, Germany) – hypo-allergenic, gluten free infant formula containing probiotic bacteria ($>10^7$ CFU/g)
- Sample 4: HiPP PRE Plus (manufactured by HiPP GmbH & Co. Vertrieb KG, Germany) – containing dietary fiber and probiotic bacteria, gluten free
- Sample 5: Novalac 1 (manufactured by UP International, Switzerland)

B. METHODS

Particle size of all infant formula samples was characterized using conventional sieving analysis. For each measurement a 100 g of powder was used. Meshes on sieves used were 500, 450, 355, 315, 280, 250, 200, 160, 140, 125,

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90, 63 μm . Sieves were manufactured by FRITSCHE, Germany. The powders were sieved for 15 minutes using Analysette 3 PRO laboratory shaker manufactured by FRITSCHE, Germany with a 2.5 mm vibration amplitude and a 3 seconds interval time.

For determination of bulk density a laboratory beaker, laboratory scale (Metler P-10 \pm 0.02 g) and a calliper were used. Samples were weighed and the height of the sample in the beaker was measured. Bulk density was calculated using Microsoft Office Excel and measurement errors were calculated using StatSoft Statistica software.

Flow properties of powdered infant formula samples were determined using TA.HD Plus Powder Flow Analyzer manufactured by Stable Micro Systems, Surrey, UK. The Powder Flow Analyzer was constituted by a vertical glass container (120 mm height and 50 mm internal diameter) and a rotating specific blade (48 mm diameter and 10 mm height), which is able to go up and down, in right or left rotation [6]. The flowability properties were evaluated during the displacement in a controlled manner of the rotating blade inside the container, filled with the powder sample [7]. Three tests were performed: quick test, powder flow speed dependency test (PFSD test) and caking test. Before testing samples were weighed and placed into a powder container in which the tests were performed. Quick test is used to determine cohesion coefficient and cohesion index. Cohesiveness is the tendency of the powder particles to cling together and agglomerate. The Power Flow Analyzer exploits this characteristic by lifting the powder. The test starts with 2 conditioning cycles followed by 3 testing cycles to measure the cohesion characteristics of the sample. The cohesion coefficient is determined during the decompression phase at 50 $\text{mm}\cdot\text{s}^{-1}$ speed while the blade moves upwards through the powder column. Cohesion coefficient is calculated using Texture Exponent 32 software by integrating the negative areas under the force/distance curve. Cohesion index is defined as the ratio cohesion coefficient/sample weight. Low cohesion index is associated with non-cohesive free-flowing powders. High cohesion index is associated with cohesive, poor flowing powders [6]. Powder categorization scale based on cohesion index is shown in Table 1.

TABLE I
POWDER CATEGORIZATION SCALE BASED ON COHESION INDEX

Cohesion Index	Flow behaviour
19+	Hardened, extremely cohesive
16-19	Very cohesive
14-16	Cohesive
11-14	Easy flowing
11	Free flowing

The PFSD test starts with two conditioning cycles followed by 5 sets of 2 cycles at increasing speeds (10, 20, 50, 100 $\text{mm}\cdot\text{s}^{-1}$) and then the final 2 cycles at 10 $\text{mm}\cdot\text{s}^{-1}$. The downward parts of the cycles compact the powder and the upward stroke of the cycle uses a lifting action. Compaction coefficients (g/mm) are

determined for each compaction cycle (at successive tip speed of 10, 20, 50 and 100 $\text{mm}\cdot\text{s}^{-1}$) by integrating positive areas under the force/distance curve [6]. The physics of compaction may simply be stated as "the compression and consolidation of a two phase (particulate solid-gas) system due to the applied force [8]. An increase in the compaction coefficient as the test speed increases indicates increasing resistance to flow and therefore flow speed dependence. Marginal or no change of the compaction coefficient with flow speed means that the powder is flow speed independent. A decrease in the compaction coefficient with increasing flow speed would mean that the powder becomes freer flowing with increasing flow speeds. The flow stability index is determined by the ratio of the compaction coefficients measured during the first and last compression phases at 10 $\text{mm}\cdot\text{s}^{-1}$ [6]. Flow stability index value close to 1 indicates the powder has not changed significantly during the test. If the flow stability index value is less than or greater than 1, the powder has undergone changes during the test. These changes may be due to attrition of the powder particles themselves or the breaking down of agglomerates.

Caking is a deleterious phenomenon by which amorphous food powders are transformed into a sticky undesirable material, resulting in loss of functionality and lowered quality [9]. Caking can result in different composites, ranging from small, soft aggregates that can be broken easily to rock-hard lumps aggregates that need a sledgehammer to disperse [10]. Cake strength depends on number of factors: packing efficiency, particle to particle interactions and moisture content. Caking test also starts with two conditioning cycles. The blade levels the top of the powder and compacts the powder column to a specified force. Compaction cycle is repeated five times and at each cycle a change in column height is recorded. Cake strength and mean cake strength are calculated using Texture Exponent 32 software. Strongly increasing cake height ratio indicates a powder that has a high tendency to cake and is likely to have a high cake and mean cake strength. A powder that has little or no tendency to cake will show no change in cake height ratio.

III. RESULTS AND DISCUSSION

Particle size is one of the most important physical properties which affect the flowability of powders. It is generally considered that powders with particle sizes larger than 200 μm are free flowing, while fine powders are subject to cohesion and their flowability is more difficult [11], [12]. The rationale behind this reduction in flowability at smaller particle sizes is due to the increased surface area per unit mass of powder. There is more surface area or surface contacts available for cohesive forces, in particular, and frictional forces to resist flow [11], [13]. Rennie et al. based their research on dairy powders and concluded that particle size affected the cohesion of dairy powders, adhesion being reduced as the particle size increased [14].

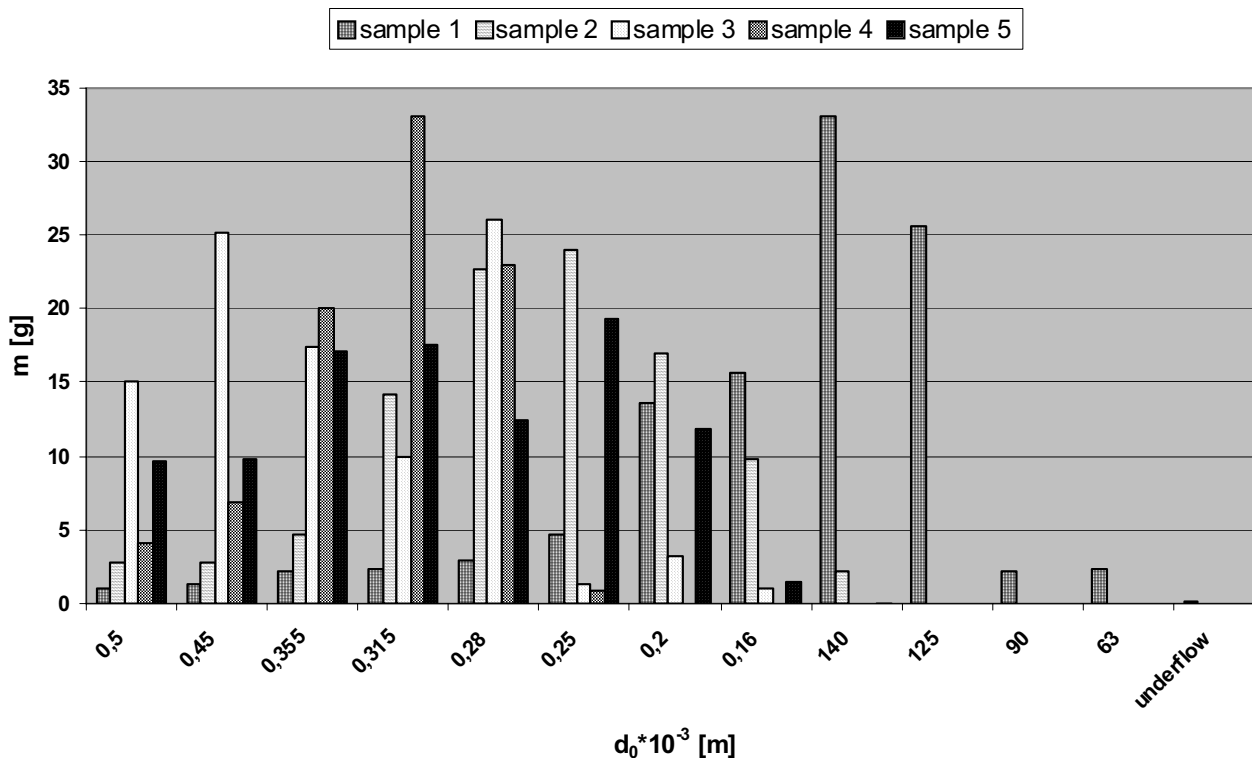


Fig. 1: Particle size of different infant formula samples

TABLE II. FLOW PROPERTIES VALUES FOR DIFFERENT INFANT FORMULA SAMPLES*

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Bulk density [kg·m ⁻³]	511.511 (±36.757)	513.162 (±87.497)	529.285 (±12.932)	413.323 (±15.011)	516.170 (±16.717)
Cohesion coefficient	-1129.825 (±104.989)	-1533.364 (±218.937)	-2431.128 (±331.601)	-1246.171 (±172.568)	-1292.512 (±163.117)
Cohesion index	-15.087 (±1.029)	-21.048 (±2.556)	-29.164 (±3.495)	-19.577 (±2.454)	-18.015 (±1.625)
Flow stability	1.09 (±0.254)	0.967 (±0.142)	1.123 (±0.070)	1.003 (±0.055)	1.117 (±0.117)
Cohesion coefficient 50 mm·s ⁻¹	-1112.25 (±79.789)	-1462.307 (±199.055)	-2191.92 (±151.192)	-1254.127 (±62.636)	-1315.313 (±168.972)

Particle size distributions of different infant formula samples are shown in Fig. 1. Samples 1, 2, 3 and 5 have a wide

particle size distribution, while sample 4 has a narrow particle size distribution. In general, powders with narrow particle size distribution flow better than powders with a wide one. It can be seen from the results of compaction and caking tests that sample 4 exhibited the best flow properties of all 5 samples

(Fig. 2, Fig. 3). However, it is important to emphasize that during sieving analysis sample 3 was extremely sticky and cohesive, so it cannot be said that sieving analysis provided reliable results for sample 3 particle size. Kwak et al. studied particle sizing by laser diffraction and concluded that dry analysis isn't suitable for infant formula particle size determination because of brakeage of particles caused by high pressure. However, wet analysis is suitable when a non-polar dissolvent is used [15]. More reliable results for extremely cohesive samples would probably be obtained by laser diffraction particle sizing.

No significant difference was found in samples' bulk density with exception of sample 4, whose bulk density was 413.323 (Table II). This sample contains dietary fiber, probiotic microorganisms and it is a gluten free sample. The lowest cake strength was determined for this sample, which was partially due to low cake height. For hypo-allergenic infant formula sample which contains probiotic bacteria the cake height ratio

was found to be slightly higher as the cycle number increased (Fig. 3). It is likely that this powder would discharge more readily after storage. Sample containing dietary fiber and probiotic bacteria (4) has the largest fraction (over 30%) of particles with a diameter of 315 μm . Powders with larger particles are not as submissive to caking as powders with smaller particles. The reason could be smaller surface area between particles and thus less possibility to inter-connect. That same sample (4) also showed the lowest and unchanging compaction coefficient with increasing tip speed (Fig. 2) which leads to conclusion that it is flow speed independent. The samples' flow speed independency is also confirmed by flow stability index, whose value is approximately 1 (Table II).

Samples 3 and 4 that are both gluten free infant formulas, despite that resemblance in composition, when comparing their flow properties, a major difference can be seen. However, as mentioned before, the sieving analysis did not give very reliable results for particle size of sample 3 because the sample was extremely cohesive and it showed the highest cohesion index value of -29.164 (Table II). It would be recommended to determine particle size of this sample with some other methods in the future research and then determine the difference between gluten free and standard samples with more accuracy. Sample that contains dietary fiber and probiotic bacteria (4) has the lowest compaction coefficient values, cake strength and the lowest cake height ratio and it is also flow speed independent. Sample with highest compaction coefficient values that decreases as the flow speed increases is the hypo-allergenic infant formula that contains probiotic bacteria (3). A decrease in compaction coefficient with increasing flow speed means that this powder becomes freer flowing, same as can be seen in all other samples, excluding sample 4. Similarity in behavior of all investigated samples could be referred to the strict composition of nutrients in starter infant formulas to which the manufacturers have to pay close attention. Samples 3 and 4 are probiotic infant formulas, with a focus on sample 3 with addition of dietary fiber. Flow properties of these two infant formulas differ to flow

properties of supplement free infant formula (sample 5), but at this point one is not able to say whether addition of probiotics or addition of dietary fiber or both are the reasons for difference in flow properties.

TABLE III
CAKE STRENGTH AND MEAN CAKE STRENGTH VALUES FOR DIFFERENT INFANT FORMULA SAMPLES^a

Sample	Cake strength	Mean cake strength
1	1343.236 (± 205.495)	36.256 (± 4.723)
2	4174.769 (± 337.178)	88.020 (± 10.727)
3	1772.287 (± 1698.283)	80.391 (± 15.559)
4	51.635 (± 6.586)	6.198 (± 1.122)
5	2123.346 (± 281.592)	77.510 (± 13.775)

^a (standard deviation values are placed in the brackets)

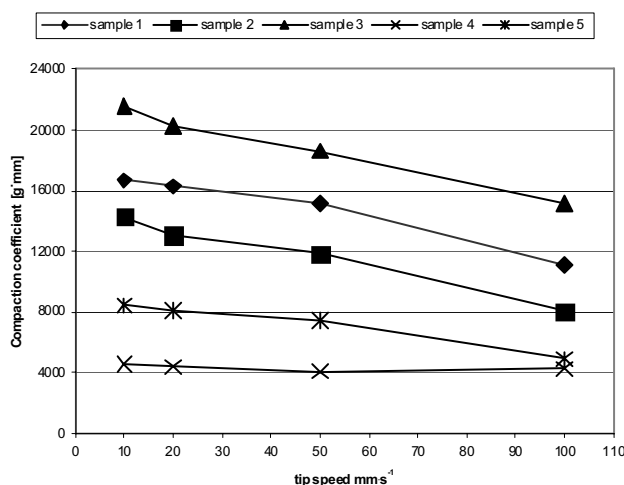


Fig. 2. Compaction coefficients of different infant formula samples

Sample (1) that is lactose free and sample (2) that contains dietary fiber show the most resemblance in cake height ratio (Fig. 3). This observation could be of great significance because sample 1 is made of smaller particles ($\sim 140 \mu\text{m}$) than sample 2 ($\sim 315 \mu\text{m}$) (Fig. 1). However, mean cake strength values show differences in caking properties, particularly lactose free sample (1) showing a lower cake strength value of 1343.236 (Table III). The difference is also visible in cohesion index values that are shown in Table 2.

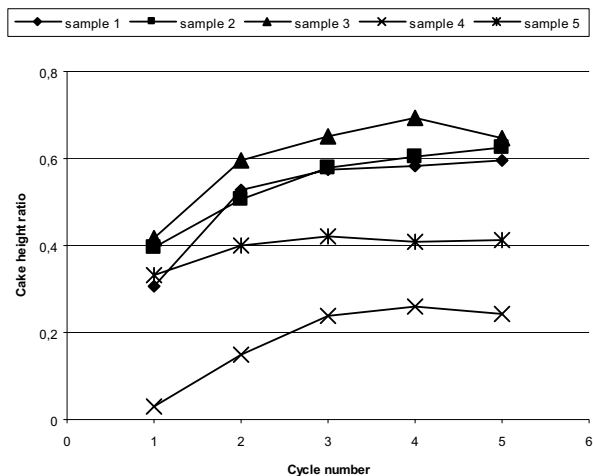


Fig. 3. Caking results for different infant formula samples

These results are opponent to those of Teunou et al., who concluded that powders with smaller particles are more cohesive and their flowability is more difficult [12]. The reason for lower cohesion coefficient index values could be the absence of lactose, known for its sensitivity towards higher temperature and humidity. In comparison with the supplement free sample (sample 5), lactose free sample (1) shows higher compaction coefficients and higher cake strength ratio. It was less cohesive than sample 5, had a flow stability index closer to 1 and a slightly decreasing compaction coefficient, which indicates that it becomes more free flowing with increasing tip speed.

IV. CONCLUSION

On grounds of investigations that were made and relying to the results obtained one can find that powders with a narrow particle size distribution show better flow properties. Sample that displays the best flow properties (4) has a disadvantage that it cannot be stated for certain whether that was because of addition of probiotic microorganisms, dietary fiber or the absence of gluten and it requires further investigations. Lactose free infant formula (sample 1) shows different flow properties than the supplement free sample (sample 5). It is very difficult to determine precise particle size composition of extremely cohesive and sticky samples. A more advanced method than sieving analysis should be used to eliminate agglomerates and to get more accurate picture for this sample type (sample 3) composition, and then the interpretation of results will be easier and more precise. Four out of five used samples had very similar values for bulk density, except sample containing dietary fibers (sample 4), who's bulk density was significantly lower. Based on obtained data one can conclude that connection between bulk density and flow properties could not be determined. Four out of five tested samples, that differed in compositions, excluding sample 4, exhibited the same tendency of decreasing compaction

coefficient with increase of flow speed, which leads to conclusion that they all become freer flowing with higher flow speeds.

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